(Some) Challenges and Opportunities in Ocean Biogeochemistry

Dorothee Bakker (d.bakker@uea.ac.uk)  
2019 WDAC meeting

Input from Tobias Steinhoff, Toste Tanhua, Rik Wanninkhof, Nico Lange, Ricard Feely, Nancy Williams, Laura Juranek, Elise Droste and Nicholas Gruber

SOCONet, SOCAT, GLODAP & SOCOM >100 contributors worldwide
Challenges and Opportunities

Exclusive Economic Zone (EEZ) data recording of e.g. surface ocean \( \text{CO}_2 \). Need for an Argo-like solution. Discussion in WMO and IOC.

Reliable access to climate data, e.g. US government shutdown.

The next step for ICOS is to become operational with near-real time data transmission. (Tobias Steinhoff)

**Undersampling of the temporal variability of the ocean carbon cycle.** Need for improved temporal resolution, a niche that BGC Argo could fill. (Nicholas Gruber)

Increasing use of sensor data. Challenges for calibration, accuracy and links between data sets (e.g SOCAT, GLODAP, BGC Argo)

OceanObs’19 - Community White Papers
NEW
IOC Working Group on Integrated Ocean Carbon Research
Supported by IOC, IMBER, SOLAS, IOCCP and CLIVAR.

Members: Chris Sabine, Maciej Telszewski (IOCCP), Rik Wanninkhof, Parvadha Suntharalingam (SOLAS), Nicholas Gruber, Laurent Bopp (IMBER), Annalisa Bracco, Wenju Cai (CLIVAR), Salvatore Arico, Kirsten Isensee (IOC)

Discussion on a (kick-of) science workshop (in 2019 or 2020)
• **Underestimates.** Partial response.
• 50% of SOCAT project funding ends in 2019.
• GLODAP heavily relies on one person.
Surface ocean CO₂ observations, data delivery and use

(Inter-)national networks, e.g. OOMD, ICOS, PICES, NIES, CSIRO

Individual projects

Observations

Data assembly, quality control and synthesis

Assessments
GCP
IPCC

Mapping, products
SOCOM

Scientific Modeling Interpretation

Distribution

Customers
Global synthesis products of surface ocean fCO₂ (fugacity of CO₂) in uniform format with quality control; No gap filling; Annual public releases; V6: 23.4 million fCO₂ values from 1957-2017, accuracy < 5 μatm (flags A-D); Plus calibrated sensor data (accuracy < 10 μatm, flag E);

SOCATv2019 (V7)
• Quality control ends 31 March 2019;
• Release on 18 June 2019.

SOCATv2020
• Data submission ends 15 January 2020.  

(Pfeil et al., 2013; Sabine et al., 2013; Bakker et al., 2014, 2016, ESSD)
Annual flux maps of ocean carbon sink
(data science)

- Surface Ocean pCO₂ Mapping Intercomparison
- 14 data-based mapping methods
- Methods differ in forcing and driver data sets.
- Annual flux maps of global air-sea CO₂ fluxes

Direct data signals

Model assumptions

Role of driver data

Bridging data gaps

Rödenbeck et al. (2015) BG
Ocean carbon sink in the Global Carbon Budget

Year to year and long term variation on ocean carbon sink. Models underestimate this variation

(Landschützer et al., 2016; Rödenbeck et al., 2015; Le Quéré et al., 2018a, b)
Uncertainty: Data coverage in space, time

The Southern, South Pacific, Indian and Arctic Oceans are undersampled. Data quality and quantity are insufficient to validate the size and variation in the sink. Air – sea ice – ocean CO$_2$ fluxes poorly constrained.

Southern Ocean (SO):

Saturation of the CO$_2$ sink
Le Quéré et al. (2007)

The SO CO$_2$ source (0.8 Pg C / yr)
(Gray et al. 2018 SOCCOM)

(Landschützer et al. 2015)
Organic and inorganic carbon transport from land to the ocean.

Changes by human activity unknown.

Organic carbon transport to the ocean (~0.78 Pg C yr\(^{-1}\)) is a major uncertainty in estimates of ocean uptake of anthropogenic carbon from pCO\(_2\) maps, e.g. for Global Carbon Budget

Coastal ocean carbon sink not well constrained.

Jacobson et al., 2007; Bauer et al., 2013; Resplandy et al., 2018
Applications of SOCAT

SOCAT is cited in >>200 peer-reviewed articles and high-impact reports.

- **Ocean carbon sink** (SOCOM, GCP, BAMS, SOCCR, IPCC)
- **Ocean acidification studies** (GOA-ON)
- **Model evaluation** (Obs4MIP, ESMVal, CMIP)
- Data products (e.g. Mercator Ocean)
- Calibration of sensors (BGC Argo, gliders)

(Bakker et al., 2016)
Global Data Analysis Project Version 2
(Interior ocean carbon and other observations)

GLODAP (1985-1999) (Key et al., 2004)

PACIFICA (Suzuki et al., 2013)


GLODAPv2.2019 (1972-2017), 840 cruises;
GLODAPv2 (1972-2013) (Olsen et al., 2016)

Release on 26 March 2019

• Uniform, bias corrected;
• Core: T, S, DIC, Alk, oxygen, nutrients, freons;
• Also: pH, carbon isotopes, organic carbon and nitrogen, tritium, helium;
• Bi-annual updates, decadal releases.
Anthropogenic carbon uptake

32 ± 4 Pg C from 1994 to 2007
160 ± 20 Pg C from 1800 to 2010

2.6 ± 0.3 Pg C yr⁻¹ from 1994 to 2007;
31 ± 4% of anthropogenic CO₂ emissions

Gruber et al. (2019) Science
Evidence for substantial anthropogenic ocean biogeochemical change
Provides insight into:
• Ocean biogeochemical change and variation
• Air-sea CO₂ flux
• Ocean acidification
A reference product for e.g.
• Climate related studies (biogeochemistry)
• Quality control of sensor data (e.g. BGC Argo)
• Model evaluation
Cited in >823 peer-reviewed articles
Biogeochemical (BGC) Argo floats

Argo sensors:
- Temperature
- Salinity
- Pressure

Biogeochemical sensors, e.g.
- Oxygen
- Nitrate
- pH
- Fluorescence
- Backscatter
- CDOM

Ice avoidance

Profiling between 0 and 2000 m depth
Send data back via satellite; lifetime up to 5 years
Calibration samples for all parameters taken as a float is deployed.
SOCCCOM is a large US NSF program using BGC Argo floats.
Biogeochemical Argo floats

SOCCOM - NSF funded

Biogeochemical Argo

Sensor Types

Latest location of operational floats (data distributed within the last 30 days)

- Operational Floats (338)
- Suspended particles (199)
- Downwelling irradiance (64)
- pH (118)
- Chlorophyll a (199)
- Nitrate (128)
- Oxygen (321)

February 2019

Generated by www.jcommops.org, 08/03/2019
pH results from SOCCOM / GO-SHIP Intercomparison
New technologies: Autonomous surface vessels
Uncertainty: Air-sea fluxes of CH$_4$ and N$_2$O, their variation, trends and drivers

Air-sea fluxes of the long-lived greenhouse gases methane and nitrous oxide, their variation, trends and drivers are poorly known.

(Wager, PhD thesis 2016)
Progression and impacts of ocean acidification (OA) by ocean CO₂ uptake

- Ocean CO₂ uptake decreases pH and the saturation state Ω for calcium carbonates (CaCO₃).
- pH has decreased by 0.1 pH unit since 1750.
- pH will decrease by 0.3 pH units by 2100 ('business as usual').
- OA will continue long after CO₂ emissions stop. OA will continue under geo-engineering, unless these reduce CO₂ emissions.
- Uncertainty on impact of OA on marine organisms and ecosystems.

(Caldeira and Wickett, 2003; Feely et al., 2009; Gardner et al., 2018)
Low and declining oxygen levels

Red: Hypoxic areas – \( O_2 \) concentrations < 63 \( \mu \text{mol L}^{-1} \) (or 2 \( \text{mg L}^{-1} \)).
Blue: Oxygen minimum zones at 300 m depth

Challenges and Opportunities in Ocean Biogeochemistry

Human activity impacts ocean biogeochemistry worldwide

Many challenges and opportunities for assessing such impacts

Photo by Brian Ward, taken in the remote Indian Ocean